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DATA FROM HANE-GENERATED RADIATION BELTS AND THE ORIGIN OF DIFFUSION THEORY

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Abstract

In this presentation we briefly review some of the published data regarding the artificial radiation belts produced by the Starfish and R2 high altitude nuclear explosions in 1962. The data showed slow temporal variations of the belts in altitude (L) and pitch angle (α) that could be modeled as a diffusion process. That early work formed the basis for more complex radiation belt diffusion models that are in use at present.

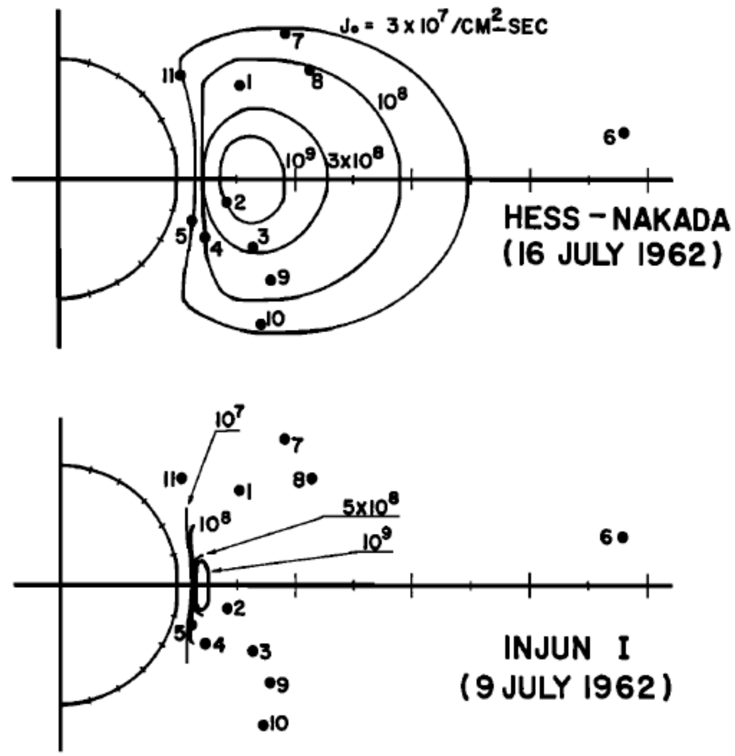
HANE Data are Well Known

- Though limited in amount and quality (by today's standards), the data revealed many remarkable features:
  - New radiation belt created;
  - Belt spreads in space;
  - Belt decays in time;
  - Lifetimes of electrons depend on L;
  - Pitch-angle distributions change in time.

- Data has been well studied and argued about.
- Data does not constrain models very much.
- Led to the development of diffusion models.

STARFISH Produced an Extended Belt

- Much old controversy about the interpretation of data from Telstar (Hess & Nakada, 1962) and Injun I (O'Brien et al., 1962)
  + Spatial extent of the belt
  + Time scale for spreading
  + Electrons out to L ~ 6 (?)



(Van Allen et al., 1963)

Trapped HANE Electron Fluxes Decay in Time

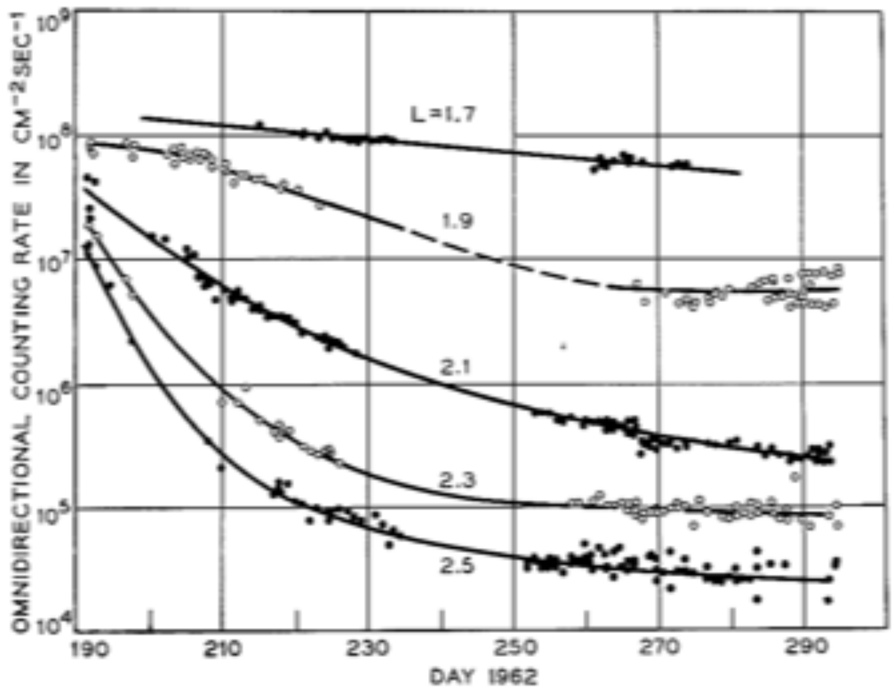


Fig. 4. The time dependence of the counting rate in narrow lamda ranges on several L lines.

Brown, 1966 (Telstar)

Lifetimes of Trapped Electrons Peak at L < 2

- The effect was evident from the HANE tests (Van Allen , 1964)
- Peak at L ~ 1.6 due to long-lived STARFISH belt
- Also occurs for naturally trapped electrons (Benck et al., 2010)

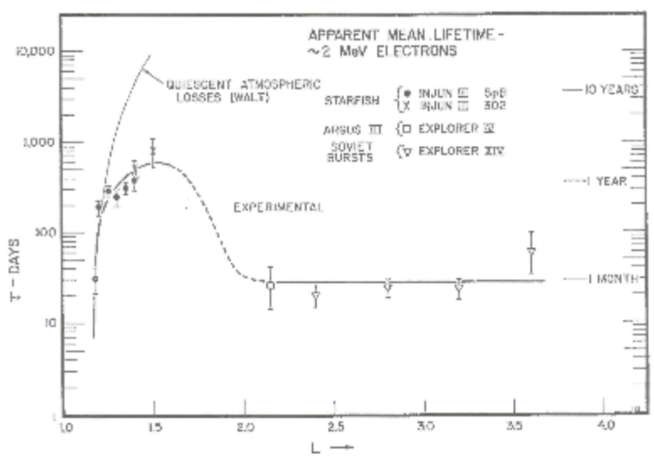
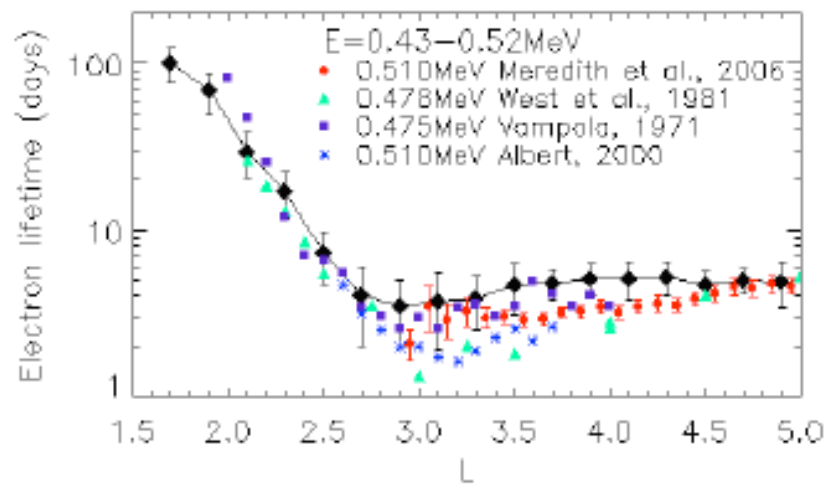


Fig. 18.



Russian R2 Burst Produced a Very Narrow Belt (in L) That Broadened in Time

- The slow rate of broadening in L corresponds to the violation of the third adiabatic invariant and suggests that it can be described in terms of a (radial) diffusion process.
- Discussed by Walt (1971) and in Schulz and Lanzerotti (1974).

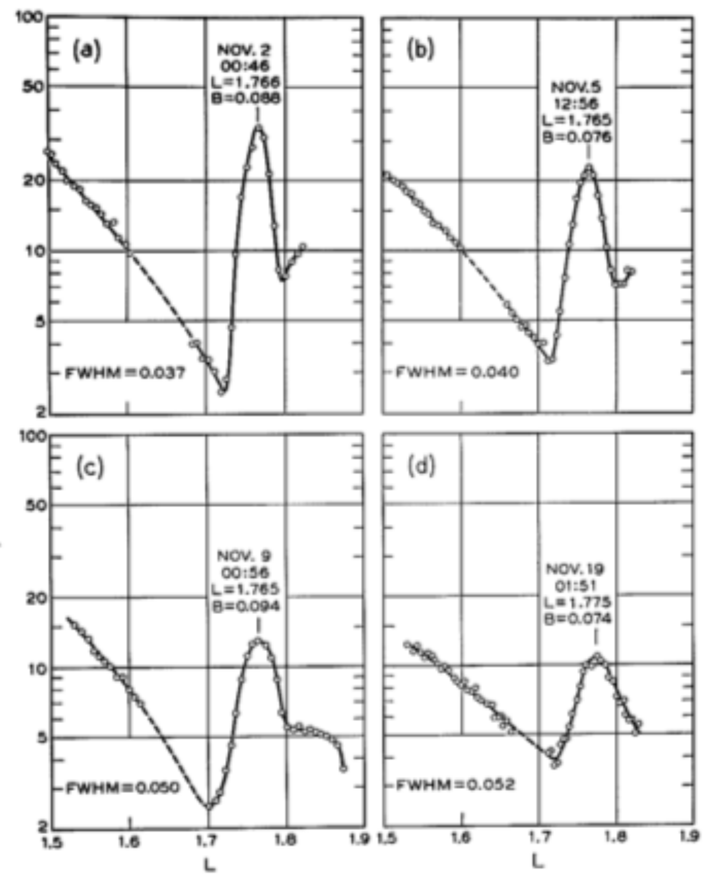
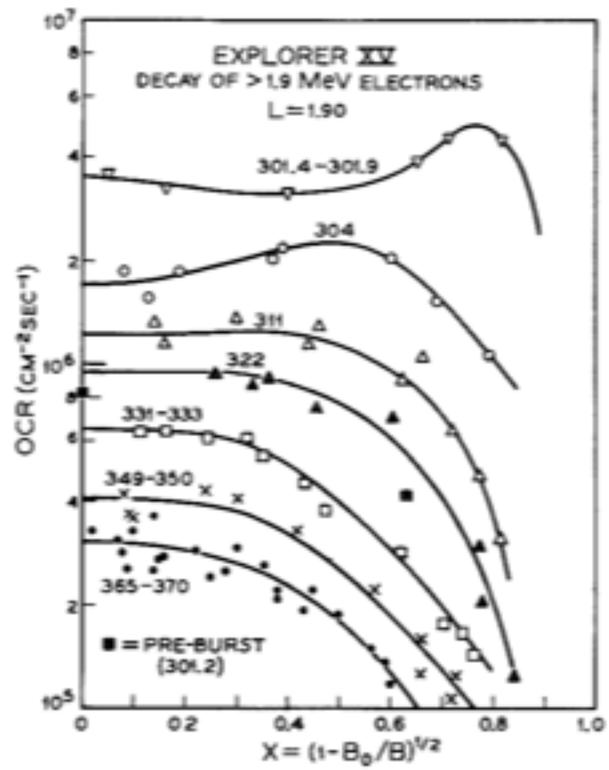


Fig. 17. Details of the narrow peak produced by the third U.S.S.R. test as observed on four passes in November. The date, time and B value of each peak center are noted as is also the full width at half maximum of a Gaussian fitted to the peak.

(Explorer XV; Brown, 1966)

R2 Data Also Showed Pitch-Angle Scattering in Time

- In this case the slow change of the pitch-angle distribution corresponds to the violation of the first and second adiabatic invariants and suggest that it also can be described in terms of a diffusion process.
- Discussed by Roberts (1969).

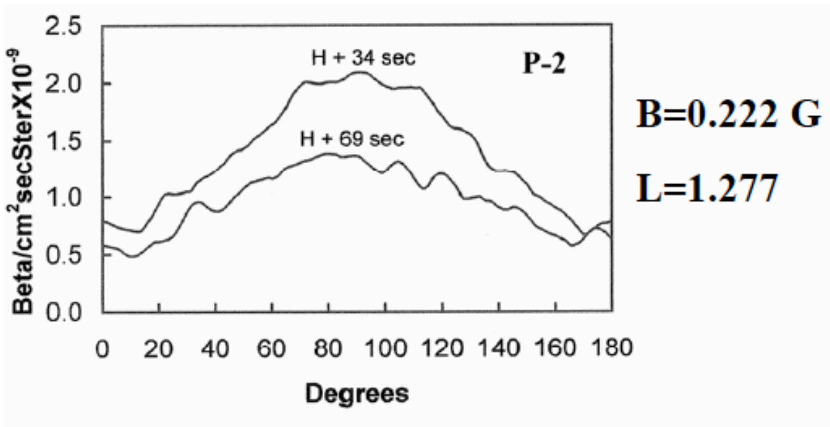


X = cos (α)

(Explorer XV; Roberts, 1966)

Rocket Data From STARFISH (Palmer Dyal, 2006) Yielded "Angular" Distributions

- Measurements of beta's (~ 2.5 MeV) at very early times (< 1 min) after the burst.
- Distributions at angles relative to spin axes of the rocket (i.e., not relative to B—not pitch angle distributions)
- Changes in the shape of the distribution correspond to evolution from omni-directional to a trapped ("pancake") distribution over a very short time. (Raw data is plotted—need to multiply by angular response function.)

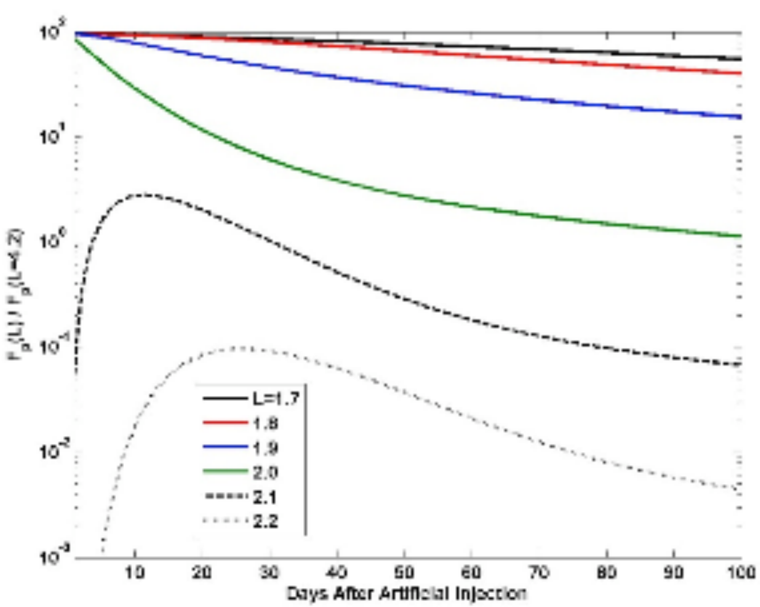


Early on, It Was Recognized That the Slow Evolution in Time Could Be Modeled as Diffusion

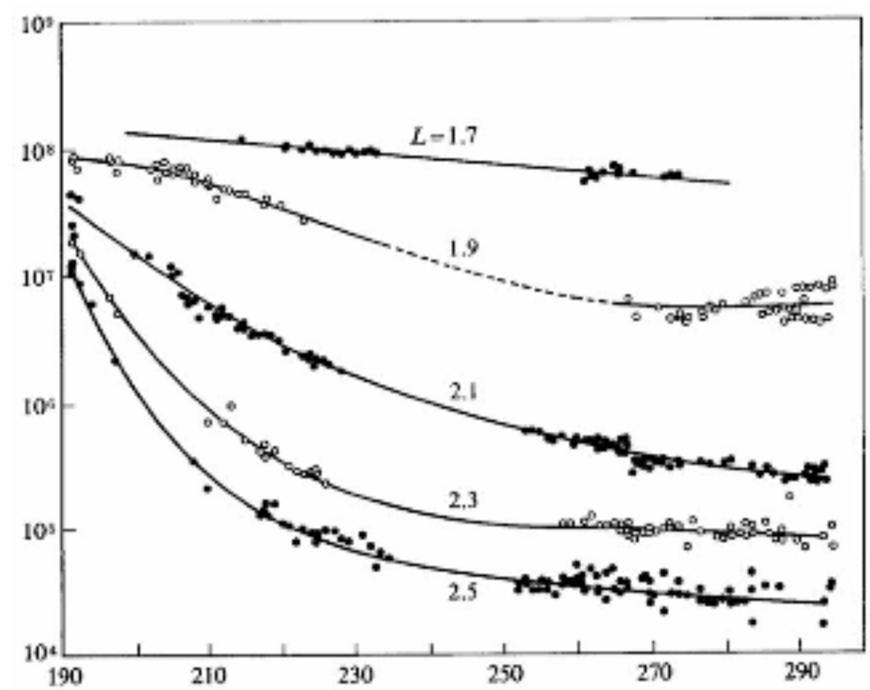
- Diffusion in L modeled with an empirical rate, $D_{LL} \sim L^{10}$ (Walt, 1971) and include a loss term (Farley, 1969).
- Diffusion in pitch-angle (α) also based a phenomenological model or on waves.
- Now, pitch-angle diffusion coefficients are mostly based on models for wave spectra (Summers, 2005).
- While reduced diffusion calculations in 1-D (α or L) are still used, 3-D calculations (α, L, E) are often done now. (LANL DREAM model: Reeves et al., 2012; Subbotin and Shprits, 2008)

Radial Diffusion Calculations Give L-Dependent Decay Rates

DREAM-HANE Simulation



TELSTAR Data

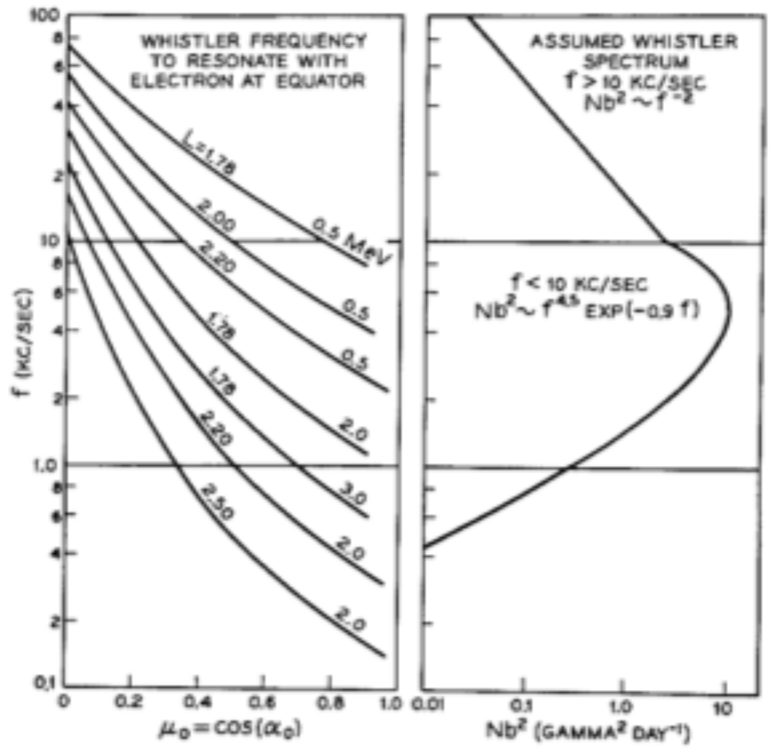


Tokar, 2010 (unpublished)

Pitch-Angle Scattering Can Be Due to Naturally Occurring Whistler Waves

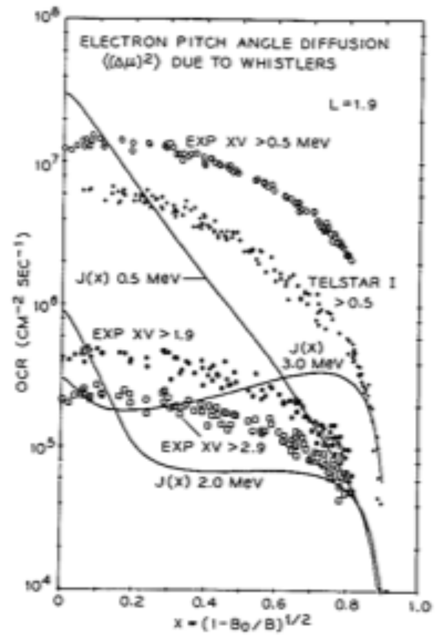
- This effect was studied early on by Dungey (1963).
- Roberts (1966) constructed a frequency spectrum based on whistler waves were in resonance with the trapped HANE electrons:

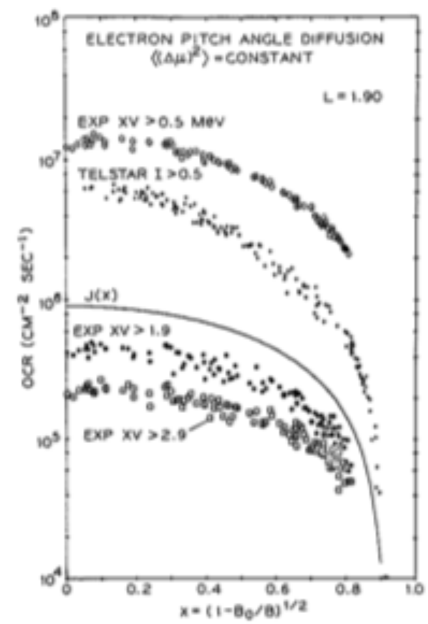
$$\omega - k_{||}v_{||} = n\omega_{ce}$$



But Computed Pitch-Angle Distributions Not Well Modeled With Whistler Spectrum

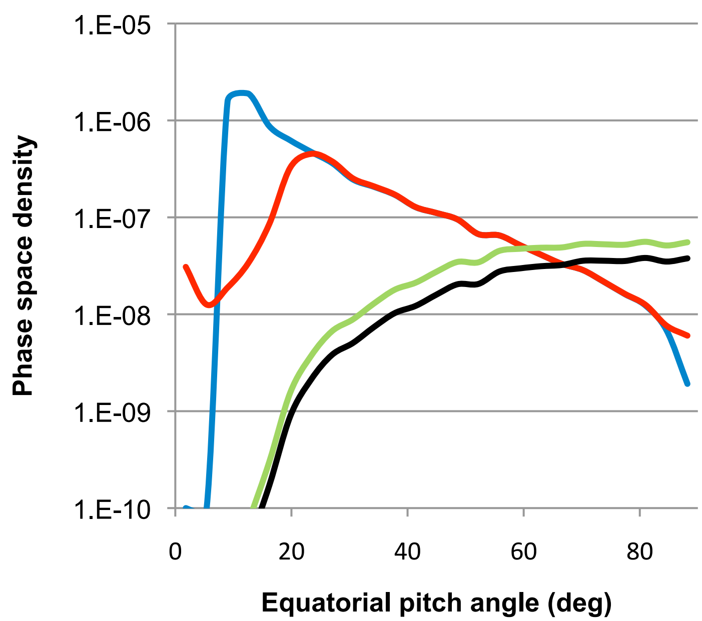
- Roberts (1966) found that pitch-angle diffusion based on a constant rate, rather than the peaked whistler spectrum, fit the R2 data better.





Our End-to-End Pitch-Angle Diffusion Code Can Model Evolution of ESM Distributions

- The ESM pitch-angle distribution is far from equilibrium.
- Pitch-angle distribution relaxes in relatively short time.
- Much of the initially trapped electrons are lost.



(Winske et al., 2011)

Lack of HANE Wave Spectra Means That Effects of Wave Particle Scattering Are Not Constrained

- What wave modes are most important? Both whistlers and electromagnetic ion cyclotron waves (EMIC) can pitch-angle scatter trapped electrons – although the resonance condition favors EMIC waves for E > 1 MeV.
- Are the waves naturally produced, or are excited (or amplified) by presence of the HANE electrons? (We will address this in later talks.)
- Belt pumping (or depletion) also occurs naturally as a result of geomagnetic substorms and remains a major unsolved issue in magnetospheric physics.

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